Galaxy Disks and Disk Galaxies
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The Assembly and Evolution of Spiral Disks

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Abstract.
We explore how the growth rate of spiral disks can be measured via analyses of the scatter in the Tully-Fisher (TF) relation of local and intermediate redshift galaxies. As an initial step, we show it is possible to construct a low-dispersion TF relation for nearly face-on, nearby spirals. We find these spiral disks are non-circular, (a mean ellipticity of 6%), which accounts for ∼0.1 mag of the intrinsic scatter in the nearby TF relation of even the most "normal" looking spirals. If this ellipticity is induced by matter accretion, we expect to find greater disk ellipticity or disturbance in the past. We find evidence that more extreme outliers of the intermediate-redshift TF relation are more morphologically and kinematically disturbed. Whether this effect reflects a redshift trend or selection bias of local samples needs to be addressed.

1. Measuring the Growth of Large Disks

Dynamically cold, large galaxy disks seen today appear to have formed early or gradually; they are easily destroyed through strong interactions or mergers. For example, Wyse (these proceedings) argues the Milky Way has not suffered a major merger in the last 10 Gyr. The nearly constant co-moving number of large disks out to $z \sim 1$ (e.g. Lilly et al. 1998) and the subtle changes with redshift in the scaling relations for large, field spirals corroborate a picture of early formation or slow, quiescent growth, but infrequent death.

The mass accretion rate onto disks is not known directly, however, at any epoch. Direct measurements of disk mass as a function of time, e.g., from measurement of disk scale-heights and stellar velocity dispersions, are desirable, but currently unavailable – except for a handful of local systems. Photometric estimates of disk mass based on colors are uncertain and incomplete. Another approach is to use the evolution of the zeropoint and scatter in disk scaling-relations as a diagnostic of *changes* in mass accretion rates. Here we focus on the correlations with, and cause of the scatter in the Tully-Fisher relation.

For gradual formation, we assume that discrete, but small accretion events perturb otherwise axisymmetric systems. Were we to obtain a complete census of galaxies at difference epochs, the relative number of perturbed systems should then reflect changes in the minor-merger rate. Zaritsky & Rix (1997) estimated the minor-merger rate for nearby galaxies by comparing the amplitude of photometric $m = 1$ modes to $B - R$ and offsets in luminosity from a fiducial TF relation. Kinematic measures of disturbance would be preferred, however, since the long-term morphological perturbation may be subtle (Haynes 2000),

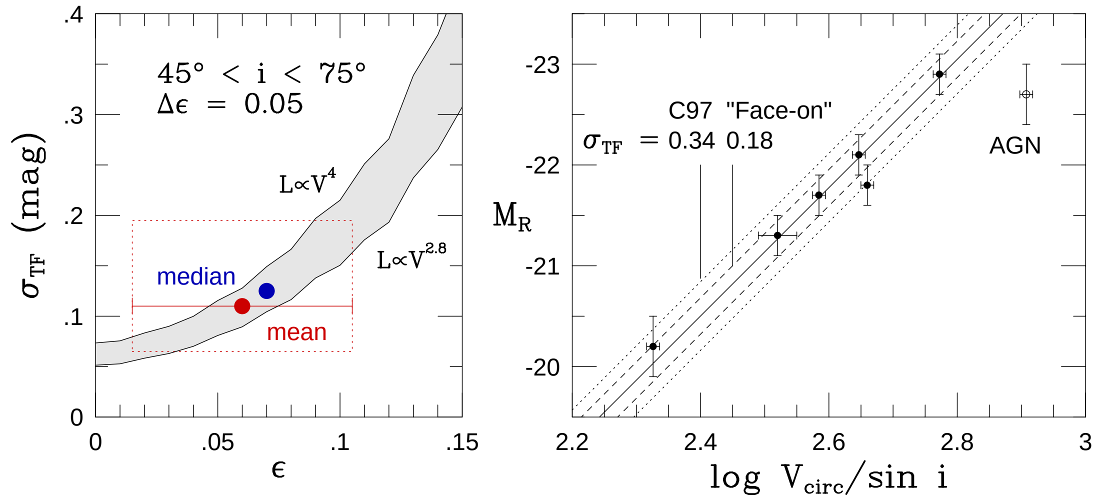

Figure 1. (a) The contribution to the TF scatter (σ_{TF}) due to inclination errors produced by intrinsic disk ellipticity (ϵ), for two TF slopes (labeled). The mean, standard deviation and median ellipticity of our sample are indicated. (b) The R-band TF-relation for our nearly face-on sample, compared to Courteau's (1997) zeropoint and scatter (assuming $r - R = 0.36$). The one outlier has an AGN and W_{50}/W_{20} line-width ratios consistent with a dynamically disturbed system (Conselice et al. 2000).

and photometric effects may evolve with look back-time due to changing gas fractions and star-formation rates (Mihos, these proceedings). Here we give two examples of how spatially resolved kinematics can directly link disk asymmetries to scatter in the TF relation. This, in turn, points to a tractable method for measuring the growth rate of spiral disks.

2. Non-Circular Disks and the Local Tully-Fisher Error Budget

Using high signal-to-noise, integral-field, echelle spectroscopy and surface photometry of seven apparently face-on spirals, we have been able to construct Hα velocity fields out to 3 scale lengths, and compare kinematic to photometric position angles, and kinematic inclinations to photometric axis-ratios (Andersen et al. 2000, and these proceedings). From mismatches between these quantities, we find that normal, non-barred, intermediate-type spiral disks are non-circular, with a model-dependent estimate of mean ellipticity at the 6% level. Considering the effects of our observed distribution of intrinsic ellipticity only on the inferred photometric inclination, we estimate this accounts for $\sim$ 0.1 mag of scatter in the TF-relation for samples selected within $45° < i < 75°$ (Figure 1a), consistent with Franx & de Zeeuw's expectations (1992).

Evidence that intrinsic ellipticity predominantly effects photometric but not kinematic measures of inclination is shown in Figure 1b. We establish a tight, R-band TF relation for galaxies with $16° < i < 32°$ by using kinematic inclinations. Not only is our zeropoint in agreement with Courteau (1997), but our scatter is smaller (albeit with a much smaller sample). Hence, it is now possible to study the TF relation for nearly face-on samples, where photometric projection effects and internal extinction are minimized, and the perpendicular component of the disk velocity dispersion can be measured to estimate disk mass.

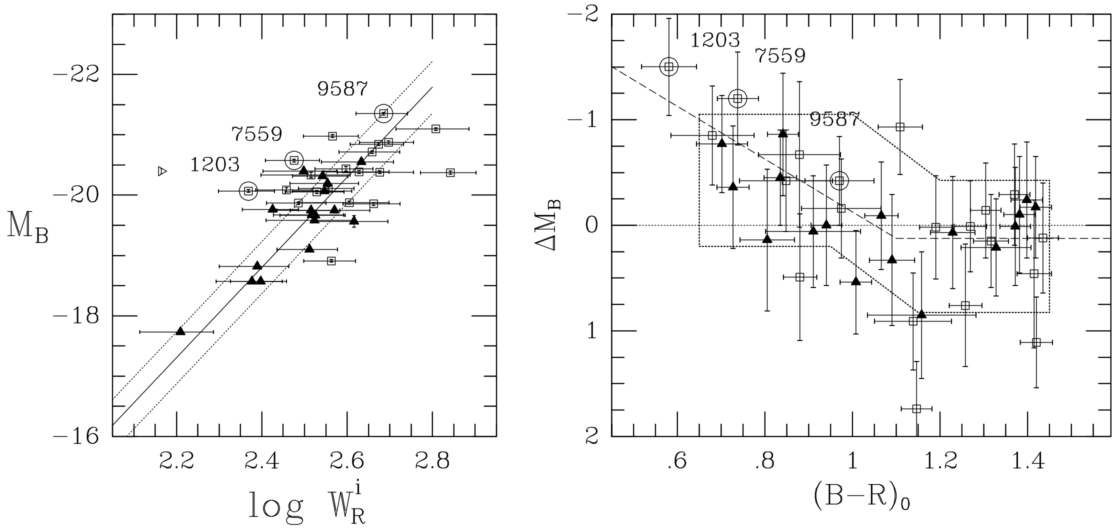

Figure 2. (a) B-band Tully-Fisher (TF) Relation for galaxies between $0.05 < z < 0.4$ ($H_0 = 68$, $\Omega_0 = 1$) compared to a local calibration (lines; Pierce & Tully 1992). (b) Residuals of this TF relation versus rest-frame $B-R$ color. The enclosed area indicates the relation found for local galaxies. For both panels: filled triangles are $z < 0.135$ galaxies, open square are $z > 0.135$ galaxies. Circled and labeled sources are shown in Figure 3. Note the good agreement between the zeropoints of the TF relation out to $z = 0.4$ (left), the clear trend of increasingly negative TF-offset with bluer color (right), yet the significant scatter about this correlation of TF residuals with color (right).

3. Scatter in the Tully-Fisher Relation at Intermediate Redshifts

An outstanding question is whether local disk non-circularity is caused primarily by small amounts of lopsided matter accretion, triaxial halos, or other dynamical processes. In principle one might hope to determine this from a detailed analysis of disk velocity fields. Alternatively, we look here to higher-redshift systems to see if greater ellipticity or asymmetry is evident, as we might expect if minor mergers are the dominant source of this perturbation.

We recently acquired high-resolution, WIYN telescope images of a representative sample of luminous, field spirals at intermediate redshifts for which we have Hα rotation-curves (e.g., Bershady et al. 1999). We find that significantly over-luminous galaxies in the $0.1 < z < 0.4$ B-band TF relation tend to appear optically distorted in the WIYN images – something we were unable to determine during the selection process based on lower-resolution images. Our definition of "over-luminous" accounts for the well-exhibited correlation of TF offsets with color (Figure 2b). Some of the most extreme outliers exhibiting pronounced optical distortions are even accompanied by clear signatures of kinematic asymmetry. A representative sequence is shown in Figure 3.

The physical connection arising here is between bluer colors and higher luminosity (i.e. enhanced star-formation), which is accompanied by increased asymmetry at extreme offsets from a fiducial TF relation. The next step is

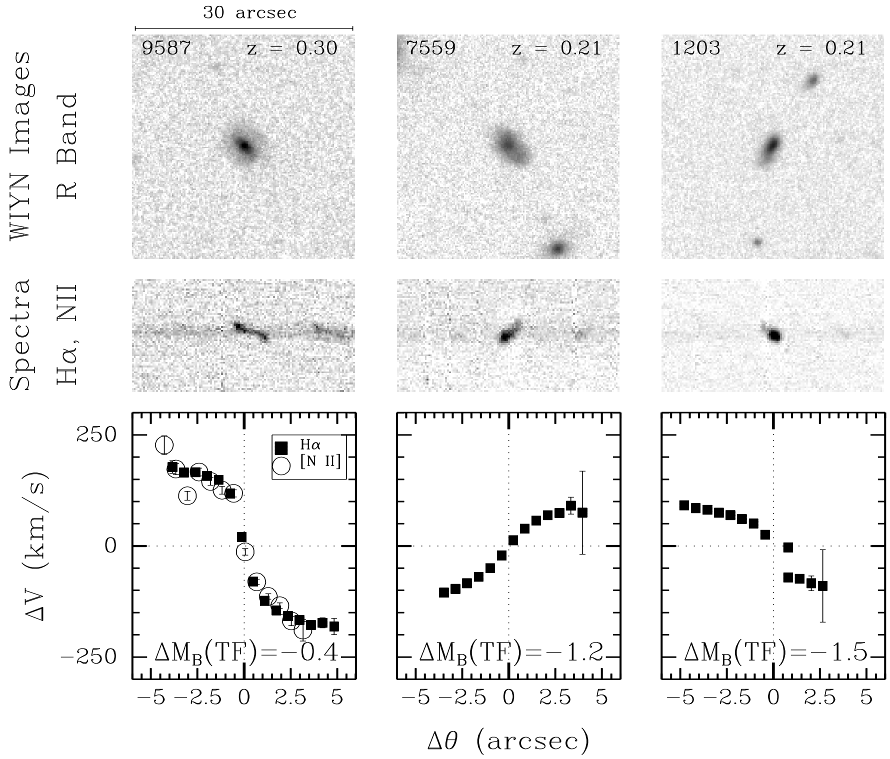

Figure 3. A sequence of three sources in our sample (circled and labeled in Figure 2) with increasingly blue $B-R$ color, increasingly large photometric and kinematic asymmetry, and increasingly large (negative) offsets from the fiducial TF relation (accounting for TF color-dependence).

to establish a statistical trend with redshift of increased asymmetry and TF offsets above and beyond changes in stellar M/L. To do so requires further observations. At intermediate redshifts, higher angular resolution is needed to detect and quantify the asymmetry in less extreme systems; precision bi-dimensional spectroscopy is needed to determine reliable inclinations. Locally, representative kinematic surveys are needed to understand the link between TF scatter and asymmetry.

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References

Andersen, D., Bershady, M., Sparke, L., Gallagher, J., Wilcots E. 2000, ApJL, submitted.

Bershady, M., Haynes, M., Giovanelli, R. & Andersen D. 1999, ASPCS, 182, 499

Conselice, C., Bershady, M. & Gallagher, J. 2000, A&A, 354, L21

Franx, M. & de Zeeuw, T. 1992, ApJ, 392, L47

Courteau, S. 1997, AJ, 114, 2402

Haynes, M. P. 2000, astro-ph/0008524

Lilly, S. et al. 1998, ApJ, 500, 75

Pierce, M. & Tully, R. B. 1992, ApJ, 387, 47

Zaritsky, D. & Rix, H.-W. 1997, ApJ, 477, 118